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Proactive, Reactive, and Inactive Pathways for Scientists in a Changing World

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Key Points:

- The implications of three pathways for scientists to respond to climate change are discussed such as maintaining trust in science
- A conceptual model is presented based on three factors: (i) potential to mitigate, (ii) impact of risk, and (iii) uncertainty in science
- A framework to assist scientists and scientific institutions to make informed decisions in response to global environmental change is outlined

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Abstract

As atmospheric CO_2 levels continue to rise so too does the risk of severe impacts. Scientists clearly have an important role to play in preparing for and responding to climate change impacts; however, calls by scientists for global action have not led to the required changes. It is timely, therefore, for scientists to critically consider their own approach toward climate change research, particularly if we are to ameliorate or adapt to unwanted outcomes. Here we present three different pathways that allow scientists and scientific institutions to conceptualize the implications of their responses to climate change scenarios. These pathways are illustrated via three plausible futures for the marine environment under climate change. This approach allows future responsibilities, outcomes, and implication to be explored within and across pathways and can be applied to different scenarios for scientists and scientific institutions to anticipate and better prepare to contribute effectively to the future.

Plain Language Summary

There is mounting evidence that impacts of climate change pose significant risks to society and human well-being. The pace of large-scale action on climate change is, however, insufficient to substantially reduce the likely future impacts. These are risks that this generation is imposing on future generations. In this context we outline a framework for scientists and scientific institutions to explore and assess the outcomes and implications of choosing different pathways (inactive, reactive, and proactive) in response to climate change. We developed three illustrative examples of plausible futures under climate change to demonstrate the implications of each of these pathways. We also outline a conceptual framework based on three factors: (i) potential to mitigate, (ii) impact of risk, and (iii) uncertainty in science that will assist scientists and scientific institutions to make informed decisions regarding their responses to global environmental change.

1. Introduction

Climate change science is broadly accepted by decision makers and society (Frost et al., 2017). The World Economic Forum listed extreme weather events, natural disasters, and failure of climate change adaptation and mitigation in the top five risks, both in terms of impact and likelihood, in the 2018 Global Risk Landscape (http://reports.weforum.org/global-risks-2018/global-risks-landscape-2018/#landscape, accessed 12 February 2018). The United Nations Framework Convention on Climate Change Paris Agreement was ratified by 195 countries in 2015, but does not explicitly outline actionable commitments for reducing carbon emissions (Mahapatra & Ratha, 2017). Without strong action, remaining 2 °C below preindustrial temperatures by 2100 seems unlikely (Clémençon, 2016), meaning that significant change to natural and food production systems is unavoidable (Cheung et al., 2016; Guiot & Cramer, 2016). The Paris Agreement did, however, overcome previous conflicts between developing and developed counties (Cornwall, 2015) and provided a trigger for increased climate change action by individual nations in the future (Clémençon, 2016). Nonetheless, climate change knowledge and concern has not resulted in global responses commensurate with warnings communicated by scientists (Rosenschöld et al., 2014) in 25 years of Intergovernmental Panel on Climate Change (IPCC) reports (IPCC, 2007, 2014), or the Union of Concerned Scientists "warnings to society" signed by over 1,500 scientists in 1992 and by over 15,000 scientists from 94% of the world's nations in 2017 (Ripple et al., 2017). In addition, scientists have publically called on the United Nations (UN) to act, as the UN Food and Agricultural Organization reports that food prices are rising and extreme climate events increasingly threaten food security (Campbell, 2014).

Changes in the marine environment are also occurring at an unprecedented rate (Hewitt et al., 2016), with increases observed in ocean temperatures and extreme events such as heat waves (Oliver et al., 2018), anoxic events (Weatherdon et al., 2016), and ocean acidification (Hoegh-Guldberg et al., 2017). It is likely that the majority of climate change impacts will have predominantly negative outcomes for society (e.g., fisheries decline (Descombes et al., 2015)). Expectations are that species invasions (Grieve et al., 2016), range shifts (Deutsch et al., 2015), extinctions (Stuart-Smith et al., 2015), coastal erosion (de Winter & Ruessink, 2017; Toimil et al., 2017), and altered system function (McDowell et al., 2016) will continue to occur in the future. These changes will affect society through alterations in the availability of food and human well-being (Blasiak et al., 2017). It is critical to develop adaptation responses to ameliorate the worst outcomes (IPCC, 2014).

Given the identified impacts and risks it would seem appropriate for scientist to focus on (1) mitigation to reduce greenhouse gas emissions, (2) adaptation to increase society's capacity to cope with changes in climate, and (3) knowledge-based efforts to learn and understand more about the manifestations of climate change impacts (Higgins, 2014). For example, there is high certainty that climate change will cause major impacts on marine systems; however, there is uncertainty around the timing, manifestation, and extent of impacts under different climate change projections. As a result, climate scenarios, such as the Representative Concentration Pathways (RCP; IPCC, 2014; Riahi et al., 2017), have been developed to describe future climate change based on greenhouse gas emissions (IPCC, 2007; van Vuuren et al., 2011). Shared socioeconomic pathways have been defined for these RCPs, highlighting the land use, energy, trade, and other broad implications under various scenarios (Riahi et al., 2017). While there have been attempts to create comparable global marine scenarios (Maury et al., 2017), regional marine scenarios with more detailed elaboration are required to underpin adaptation efforts by scientists, resource users, and decision makers.

Scientists should anticipate and assess likely changes and also work with other stakeholders to co-develop the knowledge needed to help society respond to changes (Boyd et al., 2015; Rogers et al., 2015). One obstacle to climate change mitigation and adaptation efforts has been tension between environmental, economic, institutional, and societal considerations (McDonald et al., 2018), and the agendas of different stakeholders (Holland & Pugh, 2010). Consequently, even proponents of climate change action, including government agencies setting policy and regulation, private sector corporations, and individuals, generally fail to fully implement actions consistent with scientific advice (Arvai et al., 2006; Dutra et al., 2014).

As well as providing information and advice, scientists and scientific institutions will also need to adapt. Generally, humans are challenged by understanding and valuing the long-term consequences of decisions and actions, and scientists are no different (Patrick, 2015). Foresighting is one-way scientists can co-develop scenarios, anticipate the future, and plan critical research activity (Selmer-Anderssen & Karlsen, 2016; Piirainen et al., 2016). Foresighting exercises usually aim to confront decision-makers with a set of contrasting, alternative, plausible, and coherent future scenarios that are intended to challenge assumptions that the future will be much like the present or follow a "business-as-usual" trajectory. Foresighting has a long history in corporate, military, and to some extent political circles (Hammoud & Nash, 2014), and is being increasingly applied in climate science to identify opportunities and risks in a changing world (Cook et al., 2014; Francis et al., 2011).

Our group of interdisciplinary scientists worked over a two-year period to develop ocean foresights—with a focus on the future of science, scientists, and institutions under climate change. Science here is used inclusively across the spectrum of research addressing climate change. We developed a range of foresights, but here we explore three illustrative examples of possible futures and the implications for marine scientists (as individuals) and institutions (collective groups of scientists often from private or public research organizations or universities) under climate change. We present three different response pathways (proactive, reactive, and inactive) to conceptualize the implications for marine scientists and institutions.

2. Pathways of Response for Scientists

Scientists have a spectrum of potential responses to different futures from inaction (Watson, 2016) to proactive strategies (Grant et al., 2017). In principle, scientists and scientific institutions can choose what research they conduct (i.e., what questions to address). Scientists also have choices about delivering their findings: they can publish peer-reviewed articles, write popular accounts to reach a broad audience, provide expert advice into formal institutional decision-making processes, or deliver confidential information to governments and private corporations. A preferred response is determined by an individual's personality traits, psychology, value-focused thinking (Siebert & Kunz, 2016), and by traditions and values of their institutions (Stephenson et al. 2017; Walters, 1997).

Conceptualized pathways for climate change adaptation are a foresighting approach used to support and guide informed decision-making (Fazey et al., 2015). The pathways approach has been traditionally used to emphasize the need for robust decision-making in adaptive planning and focuses on well-defined situations (Wise et al., 2014). Our pathways approach focuses on the decision-making process under uncertain conditions for determining the possible responses (proactive, reactive, and inactive) that can be taken by scientists and science institutions to adapt to potential futures under climate change (Figure 1).

2.1. Inactive Pathway

An inactive pathway approach is where scientists and institutions do not engage in research to support adaptation to climate change impacts (Figure 1). This pathway is likely to be followed when (1) there is little value placed on the system being affected; (2) the climate impacts are, or are perceived to be, low (van Putten et al., 2016; Yousefpour et al., 2017); and (3) the costs of acting outweigh the benefits that are received (Rodríguez-Labajos, 2013). The inactive pathway can also be preferred when following a reactive or proactive pathway of response would put institutions at a disadvantage (e.g., in terms of funding or opportunities) compared to their competitors (Finke et al., 2016).

2.2. Reactive Pathway

The reactive pathway is characterized by scientists and institutions operating to alleviate the undesirable impacts associated with climate change (Figure 1; Bardsley & Sweeney, 2010). Given the hysteresis of the global climate system, reactive adaptations made after an impact may be adopted too late to reduce the likelihood of additional, similar impacts in the future (Jackson et al., 2017). A reactive pathway may be an appropriate response to climate change based on cost–benefit trade-offs and could be effective when robust monitoring programs are in place to characterize impacts and evaluate management strategies (Etkin et al. 2012). The reactive pathway, however, can be slow to realize opportunities to exploit, or benefit from, in a changing world (Wickramasinghe & Gamage, 2013). Institutions, for example, can be reactive by establishing a research group when an external funding opportunity arises, rather than proactively committing to a research agenda.

2.3. Proactive Pathway

Under a proactive pathway, scientists and institutions seek evidence to reduce the risk of undesirable climate change impacts occurring in the future (Grant et al., 2017; Stockdale, 2013). Previously, proactive responses to climate change futures have not been sufficiently incorporated into strategic or anticipatory planning, due to shorter-term priorities (Hobday & Cvitanovic, 2017), and reliance on approaches embedded in existing institutional and governance frameworks (Rosenschöld et al., 2014). Proactive choices by definition rely on predictions about future events or challenges that are subject to uncertainty. For social decision-making to be proactive and scientifically informed, then scientific investment is needed to make useful predictions (Hobday et al., 2016; Salinger et al., 2016; Tommasi et al., 2017). The potential benefits of proactive approaches are becoming increasingly recognized as they can avoid some of the issues that would lead to a crisis in reactive mode alone. Proactive approaches can also give stakeholders a longer time frame to adapt, for example, in species conservation (Grant et al., 2017) and socio-economic sectors (Amelung & Nicholls, 2014), and can even capitalize on ecosystem change.

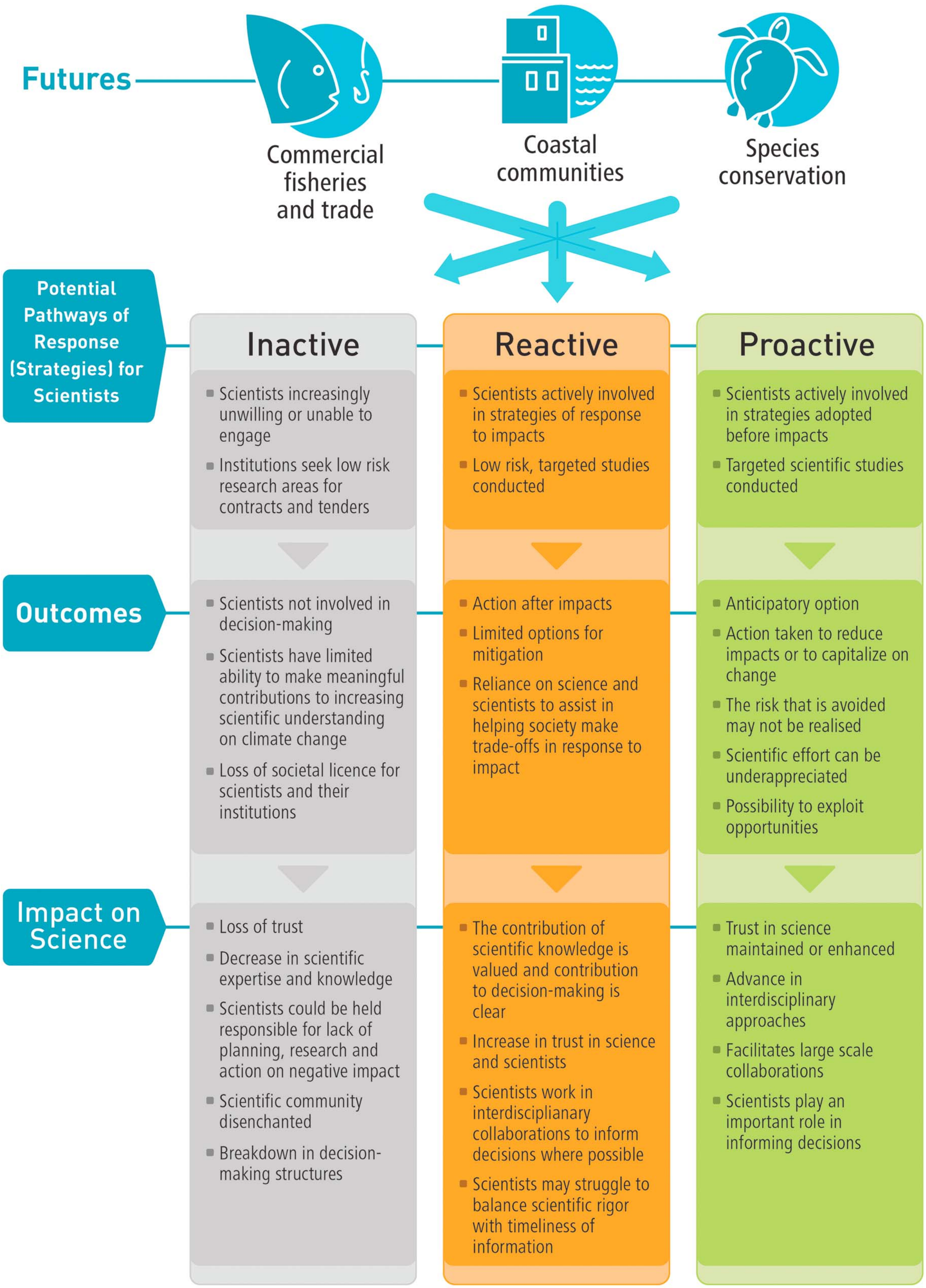

Figure 1. Climate change presents opportunity for a spectrum of pathways of response by scientists and scientific institutions to potential future change scenarios. These pathways (inactive, reactive, and proactive) have different outcomes and impact on science. The three future scenarios for the marine environment that are discussed in the text are: (1) commercial fisheries and trade, (2) coastal communities, and (3) species conservation.

3. Future Scenarios

To illustrate these response pathways we present three examples of future scenarios that provide a mechanism for individual (scientist) and collective (institutional) reflection on trajectories and possible implications of responses, such as opportunities and risks, which can arise from decisions made under uncertainty (Figure 1; Bohensky et al., 2011). In these scenarios, economic, social, cultural, and ecological values of marine systems will change and, while each scenario is discussed independently, they may also occur concurrently. These scenarios are not explicitly tied to a time period, as they may emerge at different times in different regions, but are likely within the next 10 to 50 years. Three scenarios under climate change were the focus: (1) commercial fisheries; (2) coastal communities; and (3) species conservation, as described below.

3.1. Future 1: Commercial Fisheries and Trade

Climate change predictions indicate that there will be reduced global food production (Dawson et al., 2016; Wheeler & von Braun, 2013) including seafood (Barange et al., 2014). Declining seafood stocks occur due to replacement with less palatable species, habitat modification, pollution, and overharvesting. Thus, fish markets experience increases in seafood prices as supply falls and with the cost of delivering product to market (Groeneveld et al., 2018). These effects are amplified regionally, as seafood becomes too expensive for local communities to access (Figure 1).

3.1.1. Inactive Pathway

Scientists are not involved in providing scientific evidence or expert advice to commercial fisheries and related industries to support adaptation strategies that maintain seafood supply and equitable access (Figure 1, and Figure 2). Decreasing investment in science investigating the cumulative impacts of climate change and other stressors, such as overfishing and pollution, eventually lead to impoverished marine environments and reductions in sustainable food supply. This, combined with overall decreases in the global food production, could create social conflict, with scientists unable to provide evidence that prevents adverse climate change impacts, for example, the widespread collapse of fisheries.

3.1.2. Reactive Pathway

Scientists develop responses to offset declining commercial fisheries production and the increasing cost of seafood (Figure 1, and Figure 2; Bell et al., 2013, 2017). These responses could include moving fish farms to more productive regions of the ocean and investigating sustainable methods for high-intensity farming, such as genetic modification (e.g., selective breeding) of targeted fish species, providing them with increased resilience to climate stressors, while constraining capture fisheries to reduced quotas. There is increased focus on marine resources as terrestrial-based food production also decreases with a lack of arable land and water shortages across tropical and warm temperate regions of the planet (Elliot et al., 2014; Rosenzweig et al., 2014). Scientists research and understand the nature of the impacts being experienced, such as decreased recruitment or increases in anoxic events that influence the availability and distribution of targeted fish species. Scientists, however, will have to balance the time required for scientific rigor and effort involved in collecting information with delivering that information in time for action to be taken by decision-makers.

3.1.3. Proactive Pathway

Commercial fisheries and related industries work collaboratively with marine scientists to implement artificial intelligence and technological solutions to assist with climate adaptation and transformation, to get ahead of the change, and to adapt in space and behavior in preparation (Figure 1, and Figure 2). For example, fish farms are developed that can vary animal depth with temperature and use integrated multitrophic level assemblages (to minimize waste and maximize production), and industry invests in the creation of smart methods and tools to plan, track, and catch targeted fish species. This pathway could be preferred where there is an increasing dependence on marine food sources, and acceptance that commercial fisheries as currently operating methods will fail to meet demand in the future. The outcome of this scenario is that there is confidence in climate change science, which facilitates interdisciplinary research into exploiting opportunities from the changing environment, for example, the development of new aquaculture approaches and extension of multitrophic level aquaculture to maintain food availability and support commercial fisheries industries. Anticipating the future can be risky for scientists when there are major social implications, such as sustaining food security through informing fisheries management.

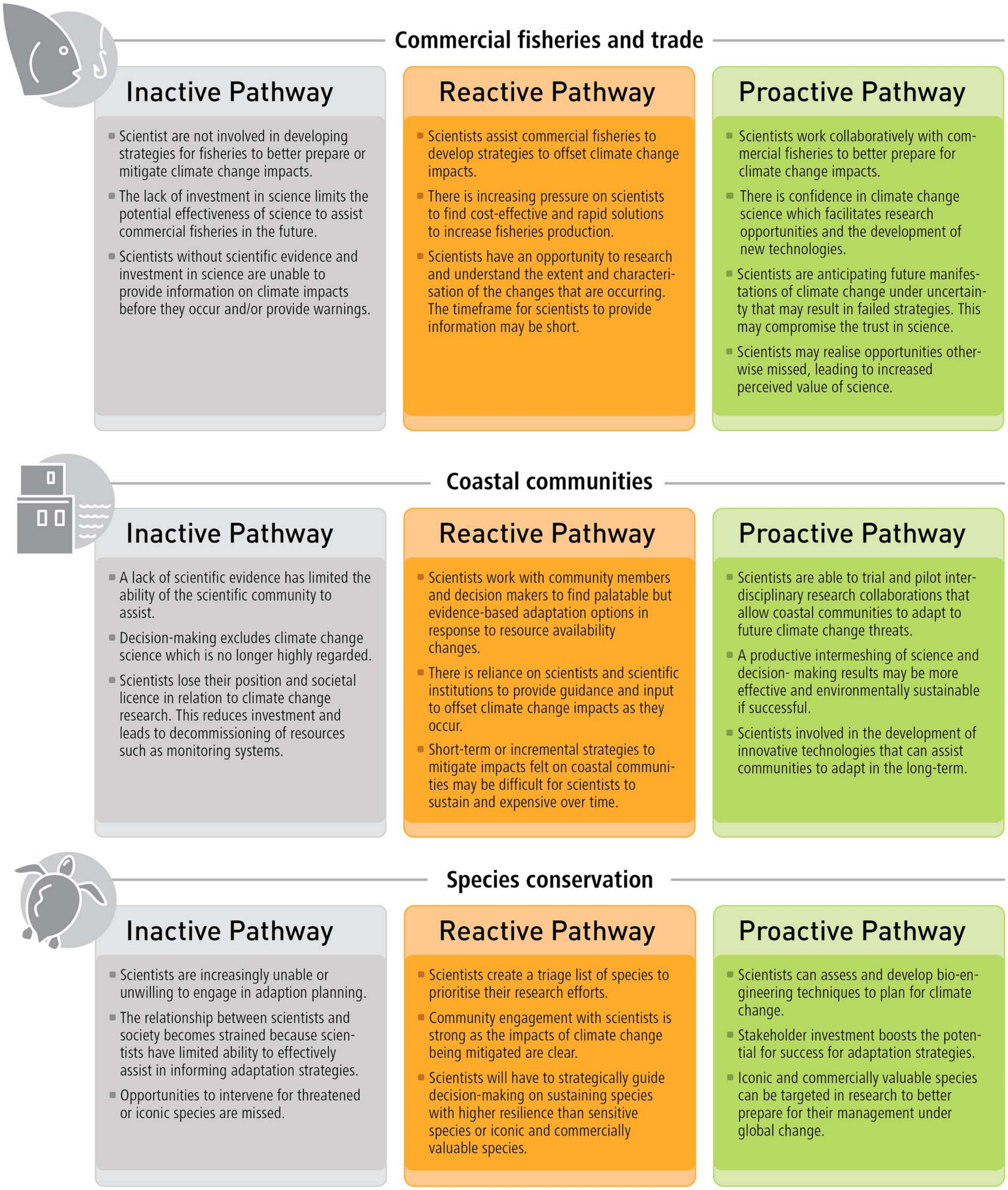

Figure 2. Outcomes of three future marine scenarios for scientists under each of the pathways in Figure 1.

3.2. Future 2: Coastal Communities

Low-lying coastal communities will be at increasing risk of inundation from sea level rise that will also increase insurance and decrease property values (Figure 1, and Figure 2; McNamara et al., 2011). An increase in the occurrence of harmful algal blooms and jellyfish outbreaks from stressed ecosystems under global change deter visitors to coastal regions resulting in harm to local economies. Recreational use of marine resources declines (due to the degraded state) leading to a change in societal behaviors. Contamination makes some seafood unsuitable for market, thereby limiting the options available to consumers (Figure 1; Groeneveld et al., 2018).

3.2.1. Inactive Pathway

A lack of investment in research results in a large amount of uncertainty and limits the ability of the scientific community to inform adaptation and mitigation strategies (Figure 1, and Figure 2). Consequently, coastal communities decline as a result of decreasing local economic activity associated with infrastructure damage from sea level rise, and the failure of local marine industries. Decision-making frameworks break down, exacerbated by the lack of investment in science. Planning by coastal communities is based on a best guess approach that involves limited scientific input and involvement. Climate change scientists reduce their influence and contribution to decision-making frameworks and society. Consequently, investment in resources, such as monitoring systems for sea level rise, is further decreased and existing scientific infrastructure decommissioned.

3.2.2. Reactive Pathway

Following significant impacts, scientists commence work with community members and decision-makers to implement adaptation strategies, such as the protection or relocation of coastal communities, and other evidence-based adaptation options, in response to inundation and resource availability changes (Figure 1, and Figure 2). These changes could include alterations to species range distributions, tourism values, recreation and increased coastal erosion. As coastal erosion intensifies there is increased pressure on scientists to provide information that can assist decision-makers and society to minimize the negative impacts of climate change. Scientists provide options to decision-makers to alleviate the immediate and short-term impacts of climate change, such as seawalls.

3.2.3. Proactive Pathway

Scientists seek approaches that allow coastal communities to adapt and even to capitalize from climate change threats before the worst impacts occur (Figure 1, and Figure 2). This research could include the development of floating and semisubmerged infrastructure for buildings and bridges. A productive partnership between scientists and decision-making emerges to offset climate change impacts before they occur. As a consequence adaptation and anticipatory actions are successful and environmentally appropriate. For example, support walls constructed to reduce erosion also provide increased habitat complexity and support the development of critical habitat, and facilitate mangrove growth in areas likely to be affected by sea level rise (Morris et al., 2018). Opportunities are identified for the strategic resettlement of coastal communities to places with increasing and stable resources, and development of innovative technologies occurs.

3.3. Future 3: Species Conservation

Altered species distributions and increased shipping bring novel species into ecosystems, making it increasingly difficult for native species to adapt to climate change pressures (Figure 1, and Figure 2). Many iconic species are experiencing the impacts of climate change, such as turtles with changing sex ratios (Abella-Perez et al., 2016; Santidrián-Tomillo et al., 2015) and albatross with declining survival (Thomson et al., 2015). The cumulative impacts of invasions, other stressors, and climate pressures in the future lead to a greater extinction risk for many species of conservation concern (Isaac & Williams, 2013). Coastal erosion from increased extreme events, sea level rise, and changes in wave energy patterns impact on the quality and area of intertidal zones and other coastal habitats, such as sand dunes and salt marshes (Clausen & Caulsen, 2014; Pendleton et al., 2011). Impairment of these habitats has detrimental effects on the biodiversity and function of coastal environments (Wetzel et al., 2012).

3.3.1. Inactive Pathway

Scientists are increasingly unable or unwilling to engage in adaptation research and planning, such as for the conservation of species that might become increasingly endangered under a predicted future climate (Figure 1, and Figure 2). This could arise where, as climate impacts intensify and available budgets for action shrink, there is a greater pressure placed on scientists to have the information before any investment is made. This new demand on scientists could result in a breakdown in evidence-based decision-making frameworks and scientists making a reduced contribution to climate change adaptation planning. Opportunities for threatened species intervention are missed as the risk of taking action that may be viewed as unsuccessful is deemed too high.

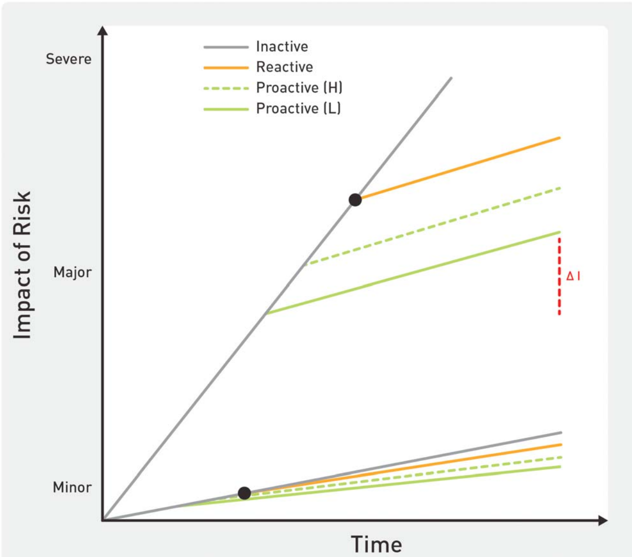

Figure 3. A hypothetical situation for two futures, one with major impact anticipated and one with a minor impact. In the case of minor impact, there is little advantage in a proactive pathway, relative to reactive or inactive pathway. For major impacts, a proactive approach taken early where uncertainty in science is low (L) leads to the greatest reduction in impacts, compared to a proactive approach where uncertainty in science is higher (H) and action might be delayed. When an event or threshold triggers a reactive pathway (bullet), the impact is decreased compared to an inactive pathway of response. The increase in impact that occurs after a pathway is taken as a consequence of time lags in ecosystem response due to historic emissions is denoted by ΔI. The potential to mitigate will become more difficult in situations with major or severe impact and a delayed response time. Our conceptual model assumes a consistent amplification of impact with time under the inactive pathway (i.e., there is no substantial increase or decrease in forcing mechanisms).

3.3.2. Reactive Pathway

Scientists create a triage list of species to prioritize their research efforts as widespread extinctions become imminent. Altered species range distributions, for example, cause localized extinctions and novel species alter ecosystem structure and function (Figure 1, and Figure 2; Mccauley et al., 2015; Wernberg et al., 2011). Scientists guide triage decisions regarding sustaining species with higher resilience to climate impacts, protecting sensitive or iconic species, or commercially valuable species.

3.3.3. Proactive Pathway

Scientists develop bio-engineering techniques to plan for species conservation under climate change (Figure 1, and Figure 2). Large-scale lime additions to the marine system to lower ocean acidification, for example, are evaluated before acidification reaches catastrophic levels. Investment in wave energy results in a decrease in carbon-intensive energy that in turn boosts the potential for success for mitigation and adaptation strategies. Stakeholder investment and collaboration in research boosts the success of these strategies. Ecotourism industries rely on scientists to provide information that can assist in the conservation of iconic species and hot spot locations. Iconic and commercially valuable species are targeted by research to help decision-makers better prepare for the future. Scientists test a diverse set of strategies, such as building artificial ecosystems or genetically modifying thermal tolerances (van Oppen et al., 2017), to aid species undergoing range shifts.

4. Future Challenges for Scientists and Scientific Institutions

Responsibility is often placed on scientists and their institutions to assess the risk of climate change and communicate this risk to the broader community (Shakhashiri & Bell, 2014). Many arguments that lead to an inactive response pathway (Figure 1) are based on uncertainty (Lewandowsky et al., 2015; Morgan & Mellon, 2011). There always will be scientific uncertainty when dealing with dynamic and complex systems, or future planning generally (Gleick et al., 2010); however, this only increases the need for robust scientific evidence to be included appropriately in decision-making under uncertain conditions (Stern et al., 2016). Risk assessments are becoming more commonly applied by scientists and decision-makers to balance future uncertainty and assess the most appropriate course of action to take under various climate change scenarios (Aslam et al., 2018; Rizzi et al., 2016; Snover et al., 2013), such as by the National Risk Register of Civil Emergencies in the United Kingdom (United Kingdom Cabinet Office, 2017). The risk assessment approach can be applied to determine which pathway of response (Figure 1) is the most appropriate to take under climate change based on the uncertainty, risk, and probability (Figure 3). The risk-based approach highlights two situations when inactive or reactive pathways should be avoided: (1) when the risk is catastrophic, regardless of the uncertainty in science, and (2) if the opportunity to mitigate in the future will no longer be possible. A further consideration is that the risk imposed by climate change increases with the time to achieve mitigation because historical emissions are already present in the system. It is possible that adopting reactive or inactive pathways will result in greater reliance on scientists and scientific institutions as effects of climate change increase (Smith & Stern, 2011). This could see scientists balancing the expectations for rapid advice from society and stakeholders with the time needed for rigorous and robust scientific investigation that informs the advice.

Deciding which pathway of response to follow (Figure 1) will be an ongoing challenge for scientists and scientific institutions and could put them in conflict with decision-making bodies and stakeholders. It will be partly determined by serendipity, personalities involved, funding opportunities, social attitudes, and willingness and the political climate. A risk assessment approach to deciding the pathway of response may assist scientists and institutions overcome these differences with stakeholders (Figure 3). There is the potential for conflict with governance bodies and stakeholders to arise if social acceptability is not considered when developing adaptation options (Hobday et al., 2015; Jones & Clark, 2014). It may therefore be necessary for climate scientists to consider four possible outcomes when choosing a pathway of response (Funtowicz & Ravetz, 1990):

1. *If scientists are inactive and a warning is not provided*, scientists could be held responsible for having exposed society to threats or missed opportunity.
2. *If scientists are reactive and provide options in response to events as they happen,* scientists may be held in high esteem for providing solutions, but it may equally result in ultimately being overwhelmed and held responsible for any costs associated or for missed opportunities.
3. *If a warning is proactively provided by scientists but not acted upon by governance bodies*, scientists may still be held responsible for not communicating the warning with enough urgency.
4. *If a warning is provided, acted upon proactively, and damage avoided*, it may lead to growing trust and rapport between science providers and decision makers and society, or efforts put into averting impacts could go unacknowledged by the broader community, potentially leading to accusations of alarmism.

In all cases it is imperative scientists continue to build and maintain relationships with managers and stakeholders (Lacey et al., 2018).

Preferred pathways may also differ between scientists and their institutions. This is exemplified when scientists seek to comment on their chosen subject or pathway. Scientists face great conflict regarding the decision to speak or stay quiet on issues that challenge society. A long-held view by some scientific agencies is that individual comment by scientific employees on policy, particularly climate policy, is not acceptable. Other individuals and institutions have strongly argued that scientists have a responsibility to speak publicly on such issues. The American Fisheries Society, for example, include a statement in their code of conduct that make the provision for individuals to speak out on occasions when their professional convictions are at odds with policies or actions of institutions (http://orafs.org/code-of-ethics/). Despite this, conflicts between scientists and their institutions are relatively common, and have led to scientists being gagged, disciplined, and in extreme cases, led to resignations or terminations of employment (e.g., Pincock, 2009). This is exacerbated by inconsistency in communication approaches across institutions. The situation could be improved with proactive planning by institutions and their scientists. Challenges identified in proactive planning include the need for institutional consensus, the merging of personal views with scientific evidence, and uninformed comments which undermine progress. With increased use of social media, scientists are more vocal in commenting on policy and societal issues (Galetti & Costa-Pereira, 2017). It remains to be seen if institutions will support individuals that comment against particular institutional policies or response pathways.

5. Outcomes of Response Pathways

There is substantial consensus in the scientific community about climatic change (Maibach et al., 2014). Nevertheless, the difficulty of transferring information on the risk, cost of inaction, and consequences of climate change to other sectors in society, and the lack of large-scale action, has led to the view that it may be too late to alter the Earth's trajectory of change, even if emissions were dramatically reduced (Sanderson et al., 2016). Scientists may have a preferred response pathway for a future, but may choose not to advocate for that pathway for fear of adverse perceptions on their credibility and role in providing information. Beall et al. (2017) found that scientists that advised on noncontroversial issues increased their perceived credibility to the public; however, scientists that advised on controversial issues received more mixed public opinions on their credibility and skepticism over their motivations. As outlined in our scenarios, it is relatively easy for scientific institutions to be reactive, directing effort and investment to areas where there is already strong demand and available funding. Institutions, however, also need to be proactive, in order to detect and anticipate future problems which are not yet apparent to society, and to produce timely information and advice for problems which are looming but have not yet attracted social priority and reaction. Melvin et al. (2017), for example, predicted that the cumulative expenditure on climate-related damage to Alaskan public infrastructure between 2015 and 2099 would decrease from \$5.5 to \$2.9 billion under RCP8.5 and from \$4.2 to \$2.3 billion under RCP4.5 with the adoption of proactive responses. A movement toward proactive pathways (Figures 1 and 3) as the default response to climate change will entail better communication of the risks and the associated uncertainty of probabilities in science and decision-making (Rabinovich & Morton, 2012). The range of possible outcomes and impacts for scientists and scientific institutions in each response pathway outlined in the future scenarios (Figure 1) highlights that both have a vested interest in the response pathways followed.

The outcomes for scientists and scientific institutions will vary not only with the response pathway (Figure 1) followed, as shown in our scenarios, but also with the timing of when scientists follow that pathway. Scientists and science institutions need to be aware that the actions taken (or not taken) in regards to climate change will alter the possible response pathways that are available to them in the future (path dependency) and, therefore, a failure to act may be seen as abrogating the responsibilities expected of scientists by society and stakeholders. In Figure 3, for example, following a reactive pathway with major risk and high certainty in science would limit the ability to change to a proactive path and thus would be an inappropriate pathway of response. Foresighting possible climate change futures, such as the examples provided in this paper (Figure 2), exploring pathways of response (Figures 1 and 3) may assist scientists and scientific institutions to conceptualize the possible outcomes of theses futures and plan the science needed to support the most appropriate pathway, and to identify actions needed to improve the probability of a positive outcome.

Science should focus on process-based knowledge generation (Crowley, 2013) to support a reactive or proactive pathway. Overstating or sensationalizing research findings may seem appealing to individuals or institutions due to funding or promotional systems (Hein et al., 2018); however, a potential outcome is distrust. Rising distrust could restrict the ability of scientists and scientific institutions to fulfill their roles and responsibilities to society. Rigorous and robust research findings into the impacts of climate change on environmental processes and resulting management actions are important in selecting the correct pathway and to prioritize new investigations into issues with the highest risk (Figure 3; Gupta, 2016; Kabat, 2017). Maintaining the integrity of climate change science with transparency, thorough peer review, and trustworthy communications will increase the effectiveness of science in assisting society to prepare and the future well-being of the planet (Barbier et al., 2018).

Public perceptions and trust in climate science suffered in the wake of "climategate" (the unauthorized disclosure of e-mails between scientists in the United Kingdom and United States and active campaigns to misrepresent the content of some of those e-mails; Garud et al., 2014). A high public regard, however, remains for scientists and climate science (Leiserowitz et al., 2013). The ability of scientists to play a role in climate change decision-making relies on their capacity to provide credible information in a timely manner and when appropriate, which facilitates the development of trust among stakeholders (Anonymous, 2010; Lacey et al., 2018), and will be influenced by the response pathway followed in Figure 1 and its success. A loss of trust will reduce the influence of scientific information and the role of scientists in decision-making. Therefore, following pathways of response that foster trust in science and scientists will be important for understanding and acting on climate change in the future. Successful and effective scientific input into a sector not only increases trust and demand for science, but ideally makes the sector more successful and sustainable, increasing its capacity to support science (Pielke, 2007).

Scientists and scientific institutions need to envision the future of climate science and assess possible scenarios that can unfold under global environmental change. Reflecting on the responses that scientists and scientific institutions could take to these future scenarios could not only provide a basis for strategically assessing the possible outcomes of each pathway but also allow scientists and scientific institutions to guide their choice of pathway to better prepare for global environmental change.

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